NORTH CAROLINA
DEPARTMENT OF WATER RESOURCES

DIVISION OF GROUND WATER

REPORT OF INVESTIGATIONS NO. 3

GROUND-WATER SUPPLY FOR THE DARE BEACHES SANITARY DISTRICT

By

JOEL O. KIMREY

RALEIGH

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NORTH CAROLINA
DEPARTMENT OF WATER RESOURCES
Harry E. Brown, *Director*

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Harry M. Peek, *Chief*

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JOEL O. KIMREY

Hydraulic Engineer

U. S. Geological Survey

PREPARED IN COOPERATION WITH THE GEOLOGICAL SURVEY

UNITED STATES DEPARTMENT OF THE INTERIOR

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1961

NORTH CAROLINA

BOARD OF WATER RESOURCES

STATE OF NORTH CAROLINA

DEPARTMENT OF WATER RESOURCES

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HARRY E. BROWN, DIRECTOR
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RALEIGH N. C.

OFFICE OF THE DIRECTOR

The Honorable Terry Sanford
Governor of North Carolina
Raleigh, North Carolina

Dear Governor Sanford:

I am pleased to submit Report of Investigations No. 3, "Ground-Water Supply for the Dare Beaches Sanitary District, North Carolina," prepared by Mr. Joel O. Kimrey, United States Geological Survey.

This report gives the results of a study to evaluate the ground-water resources of the Dare Beaches Sanitary District. It also presents recommended procedures for developing and protecting sources for a central water supply for the District.

Respectfully submitted,

Harry E. Brown

Harry E. Brown

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GROUND-WATER SUPPLY FOR THE DARE BEACHES SANITARY DISTRICT, NORTH CAROLINA

By

Joel O. Kimrey

INTRODUCTION

In 1958 the Dare Beaches Sanitary District through its Chairman, Mr. P. J. M. Bayne, requested the aid of the North Carolina Department of Conservation and Development in obtaining an evaluation of the ground-water resources of the district, which is on Bodie Island, Dare County, N. C. (fig. 1). In response to this request the North Carolina Department of Conservation and Development arranged for the U. S. Geological Survey to undertake the evaluation of the ground-water resources of the area as part of the cooperative program between the two agencies.

The Dare Beaches Sanitary District was created by the State Board of Health in 1949 under authority of Chapter 100, Public Laws of 1927, and later amendments. In 1955, authorities of the Sanitary District became interested in developing a central water-supply system to replace individual supply systems. Existing supplies, principally obtained from shallow well points, were becoming inadequate to meet the increased need for water brought on by the population growth in the area. Shallow-well supplies along the beach developments were subject to pollution from waste-disposal systems, owing to the large number of these systems in crowded areas. In addition, excessive withdrawal of ground water anywhere in the district might result in salt-water encroachment because of the nearness of salt water in the ocean and the sounds.

Field work for the investigation was done during the final months of 1958. Test wells were drilled with a power auger at selected locations to determine the extent of the lithologic units and the depth to salt water. Analysis of data collected during preliminary drilling determined the areas where additional drilling would delineate the fresh-water bodies. Work on the investigation and the preparation of this report was done under the immediate supervision of P. M. Brown, district geologist of the U. S. Geological Survey, Raleigh, N. C.

Acknowledgments

The writer wishes to acknowledge the courteous cooperation of officials of the Dare Beaches Sanitary District and field personnel of the State Board of Health during the course of the investigation.

Test drilling

During the investigation, 96 test wells were constructed in the area of investigation (pl. 1).

Sixty-seven wells, ranging in depth from 98 to 128 feet, were drilled along 13 east-west lines that extended from ocean to sound. These lines were spaced at an average distance of slightly more than a mile apart normal to the 15-mile length of the district.

Rock samples and water samples obtained from these wells identified the area containing the largest body of fresh water and the best potential aquifers (fig. 3). The northern limits of this area begin near the U. S. Coast Guard Station on Bodie Island. It extends southward 3 miles to Jockey Ridge, and westward from U. S. Highway 158 to the Nags Head Woods. Twenty-nine wells, ranging in depth from 40 to 103 feet, were drilled in this area to determine the continuity of the sediments and the extent of the fresh-water body. The shallower wells were drilled to trace the continuity of the sands yielding fresh water and the deeper wells to determine the depth to salt water.

Rock samples were collected at 5-foot intervals from all test wells. Water samples were collected, whenever possible, from each lithologic unit encountered in each well. The chloride content of all water samples was determined by field test and laboratory analysis by the U. S. Geological Survey. Records of the analyses of water samples, together with the rock samples from all test wells, are on file at the office of the Ground Water Branch, U. S. Geological Survey, Raleigh, N. C.

GEOGRAPHY

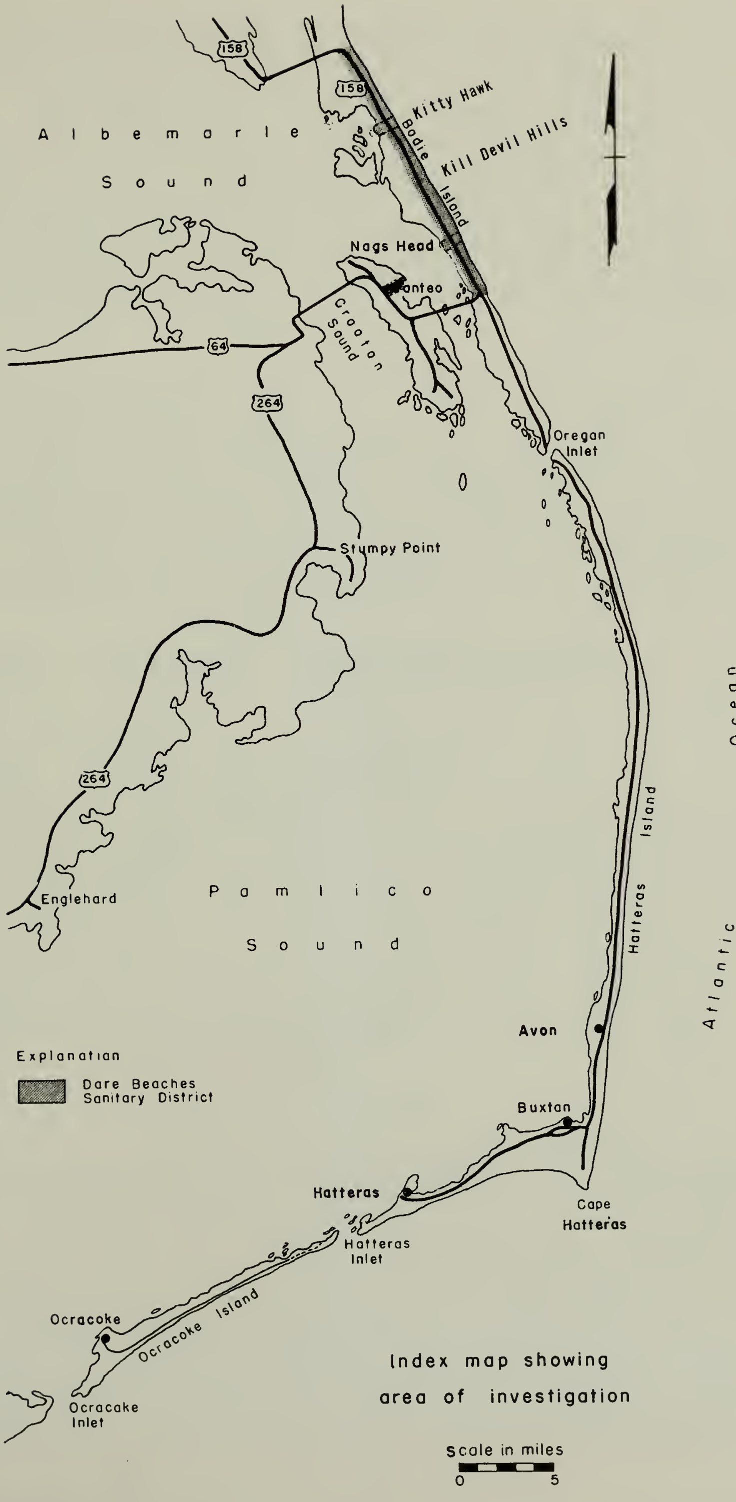
Location

The Dare Beaches Sanitary District is in the east-central portion of Bodie Island, Dare County, N. C. This part of the island is bordered on the east by the Atlantic Ocean and on the west by Currituck Sound, Albemarle Sound, Kitty Hawk Bay, Buzzard Bay, and Roanoke Sound (fig. 1 and pl. 1). U. S. Highway 158 parallels the ocean beach in the sanitary district; the highway at all places is less than 1,000 feet west of the beach as it traverses the 15-mile long district. The sanitary district ends at the north where U. S. Highway 158 turns west toward Wright Memorial Bridge and on the south at Whalebone Junction where U. S. Highway 158 is joined by U. S. Highways 64 and 264 (pl. 1). Throughout most of this area the sanitary district extends from high tide at the ocean beach westward to a line 700 feet west of U. S. Highway 158. Boundaries of the sanitary district deviate from this pattern at two locations, one in the northern part and one in the southern part of the district. At these places, the district boundaries extend westward to the sound side of the island to include sound-side beach developments. The area within the limits of the district includes most of the developed properties north of Whalebone Junction, except for Kitty Hawk Village. This village is located west of the district. The incorporated town of Kill Devil Hills, the village of Nags Head, Kitty Hawk Beach, and various other beach developments are located within the district.

Bodie Island is the northernmost member of a group of coastal islands known as the North Carolina "outer banks." These islands, which are barrier beaches between the Atlantic Ocean to the east and the various sounds and bays to the west, form the eastern rim of the State.

Topography, precipitation, and drainage

The eastern edge of Bodie Island is a relatively straight strip of ocean beach trending generally north-northwest. Various bays and tidal marshes indent the west side of the island, causing it to vary markedly in width. Adjacent to the sanitary district, the width of the island ranges from a maximum of almost three miles near the northern limit to a minimum of less than half a mile at Whalebone Junction near the southern limit. Shifting sand dunes blanket the island in all areas not stabilized by vegetation. Elevations range from sea level in the sound-side marshes to more than 100 feet above sea level on some dunes such as Engagement Hill (elevation 138 feet). The elevation of the strip along the ocean beach composing most of the sanitary district averages about 10



Index map showing area of investigation

Figure 1

feet above mean sea level. The Nags Head Woods in the west-central portion of Bodie Island are forest-covered dunes having elevations up to about 70 feet. A 35-acre lake known as Fresh Water Lake and numerous smaller fresh-water lakes occur in this wooded area; they are water-table lakes occupying wind-scooped depressions.

The average annual precipitation in the vicinity of the Dare Beaches Sanitary District ranges from 44.05 inches at nearby Manteo to 47 inches in the northern part of the district (fig. 2). Precipitation is greatest between July and October.

The surface sands of the area have a high permeability, which results in rapid absorption of rainfall. If surface runoff occurs at all, it is probably confined to the tidal marshes bordering the sound-side of the island. Rainfall moves directly downward to the water table and discharges by lateral seepage into the ocean, sounds, and bays.

Population

The permanent population of the area is small compared with the number of summer residents. The summer resident population has risen from an estimated 3,200 in 1949 to 8,200 in 1957. The number of winter residents is much smaller, but they also have increased steadily during the same period. In addition to property owners who maintain summer residence, the summer population is increased by the large numbers of vacationers who rent lodgings.

Data tabulated by the Southern Mapping and Engineering Co. of Greensboro, N. C., are shown in the following table. These figures pertain to the increase in potential water customers from 1950 to 1957.

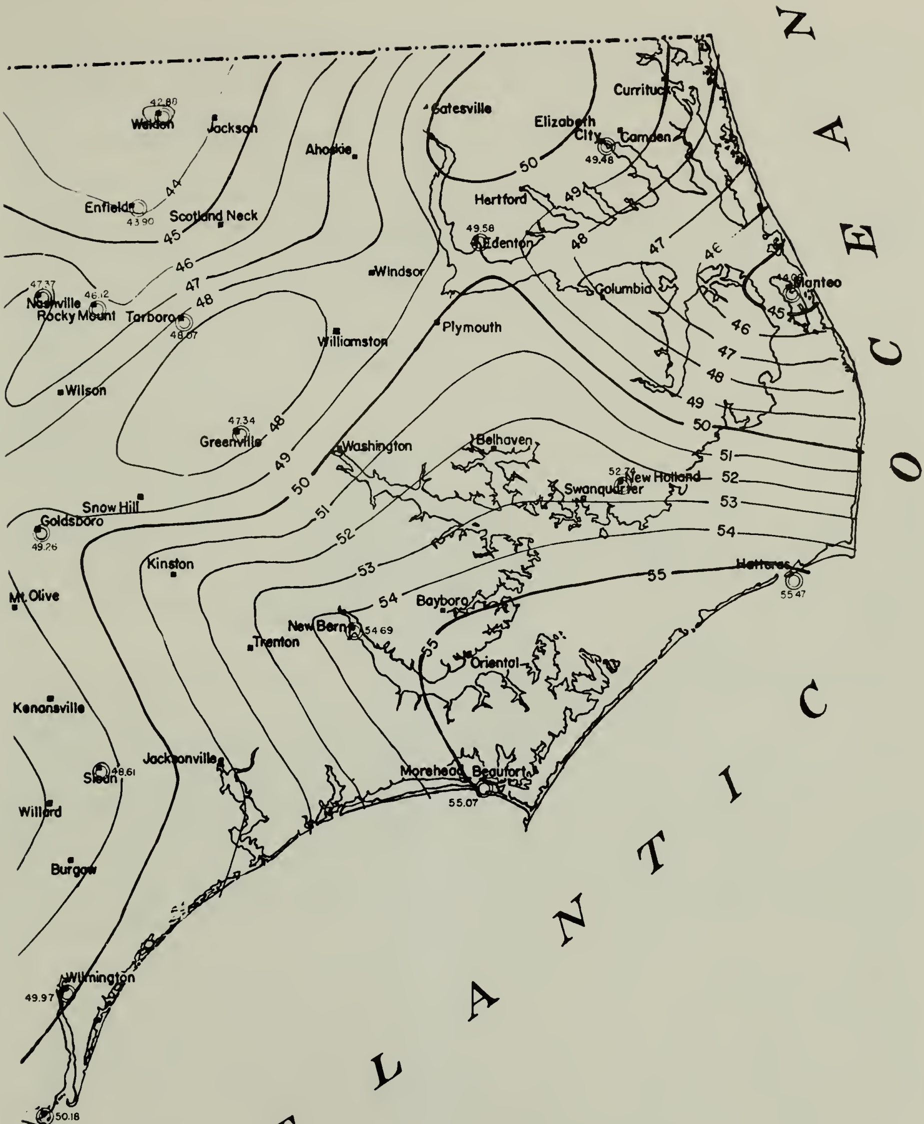
YEAR	HOTELS AND MOTELS	STORES AND BUSINESSES	COTTAGES AND RESIDENCES	POTENTIAL CUSTOMERS
1950	30	32	498	560
1957	62	64	1,510	1,636
Increase	32	32	1,012	1,076

The sanitary district is expected to continue its population growth because of its location. The Cape Hatteras National Seashore Recreational Area south of the district offers a scenic beach wilderness having camping and beach facilities. Historical attractions in the area include the Kill Devil Hill National Monument, site of the first airplane flight by the Wright brothers, on Bodie Island; and the Fort Raleigh National Historical Park, site of the first English settlements in America, on nearby Roanoke Island. Waterfowl hunting and fishing attract sportsmen during the open season. U. S. Highway 158 is one of the main access routes to the "outer banks" region. A new highway paralleling 158 through the sanitary district currently is being built to accommodate increased traffic.

GEOLOGY

Three separate lithologic units, all of Recent age, are identifiable over all or part of the area. They are a lower unit of dark-gray silty sand and an upper unit consisting largely of clean light-gray sand. A coarse-grained beach gravel interfingers with the upper unit.

The depth below the land surface to the lower unit averages 45 to 50 feet in most of the area of investigation. None of the test wells completely penetrated this unit. Typically, it consists of medium to fine-grained well-rounded quartz sand interbedded with thin layers of silt which at a few places grades into clay with depth. The amount of silt shows a wide lateral variation. Samples from wells near Kill Devil Hill show 10 percent or less silt. Silt percentages in other areas are as much as 40 percent. Vertical variation in silt content also is apparent in many well sections.



North Carolina

State Board of Water Commissioners

AVERAGE ANNUAL RAINFALL

1921–1955

Figure 2

Scale in Miles

10 0 10 20 30 40

Ordinarily the percentage of silt in this unit increases downward, but in some wells the amount of silt decreases with depth. Correlation between adjoining well sections is made difficult by lenses of clean sand, as much as 5 feet thick, that occur at random in this unit. Clay layers, ranging in thickness from 2 to 9 feet, were penetrated at depths ranging from 60 to 100 feet below the land surface in wells 60, 61, 41, and 63 (pl. 1), in the western part of the area drilled. Clay layers more than 2 feet thick were not penetrated in other areas. The effects of compositional variation in this unit on the movement and quality of ground water are discussed in the section below entitled "Ground Water".

The upper unit is a clean light-gray medium to fine-grained quartz sand containing disseminated shell fragments in its lower 10 feet and grading into a tan iron-stained sand in its upper 10 to 15 feet. A coarse beach gravel interfingers with the medium to fine-grained sand along part of the eastern limit of the upper unit. The beach gravel consists of 15 to 75 percent rounded shell fragments and coarse gravel-size quartz fragments in a medium to fine-grained sand matrix. This coarse material was penetrated by test wells in an area that extends south along the ocean beach from Kill Devil Hill to Whalebone Junction and to the new highway on the west (pl. 1, fig. 3). The beach gravel has an average thickness of about 5 feet near its western limit and thickens to a maximum of about 30 feet beneath the ocean beach. It is underlain and overlain by the light-gray medium to fine-grained sand. Throughout the area the depth to and thickness of the beach gravel both vary by as much as 15 feet in some test wells less than a thousand feet apart.

GROUND WATER

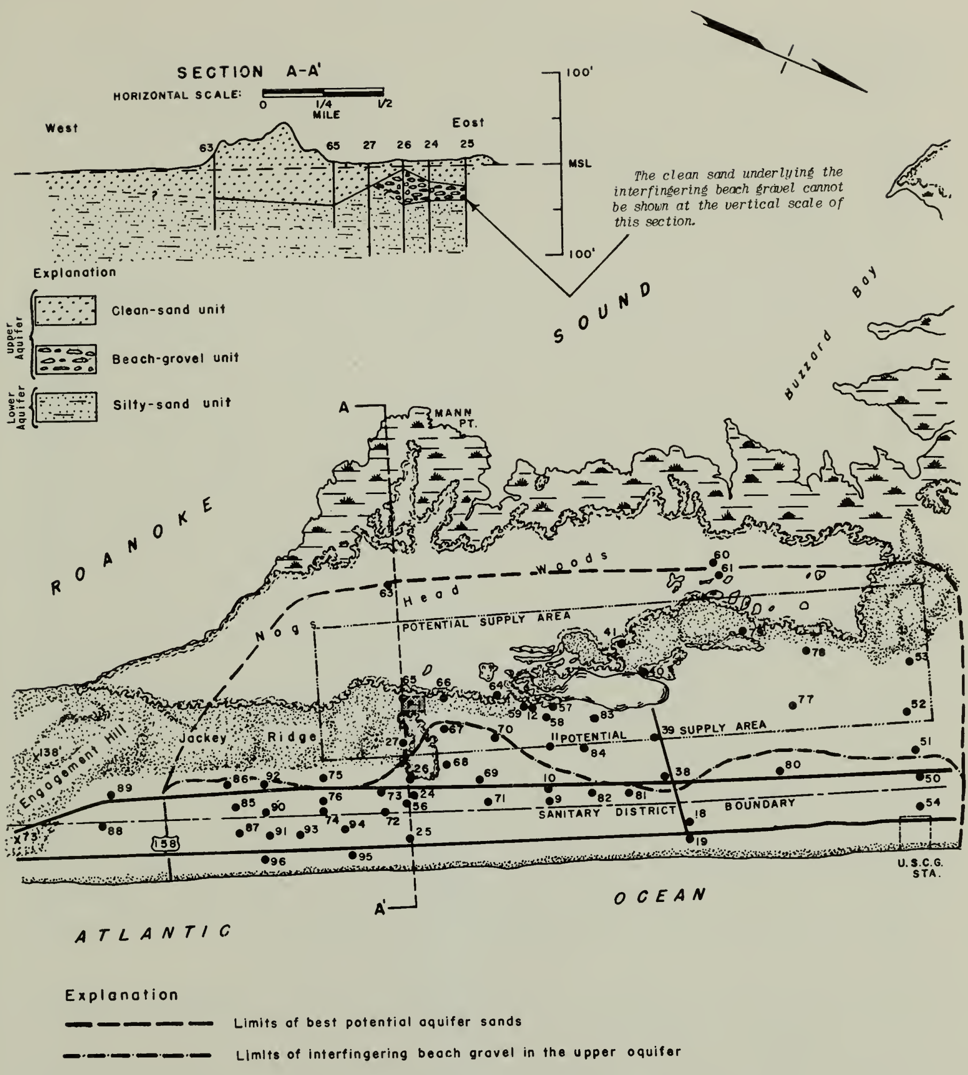
Ground water is the subsurface water in the zone of saturation -- the zone in which all pore spaces are filled with water under hydrostatic pressure. An aquifer is a rock layer or group of layers that are water-bearing -- that is, capable of transmitting usable quantities of water to wells and springs.

When precipitation falls on the land surface, a part of it runs off directly to streams and lakes, a part is lost by evaporation from the surface, and a part enters the soil. Of the part that enters the soil, some is retained and later discharged by the transpiration of plants. The remainder continues downward under the influence of gravity to the zone of saturation, the top of which is called the "water table." Water in the zone of saturation moves laterally to a place of discharge such as a well or a spring. The lateral movement of water in an aquifer may take place under either nonartesian or artesian conditions. Where ground water does not completely fill a permeable formation, its surface, which is at atmospheric pressure, is free to rise and fall. Such ground water is said to occur under nonartesian, or water-table, conditions. If ground water completely fills a permeable formation that is overlain and underlain by a relatively impermeable bed, or aquiclude, its surface is not free to rise and fall and the water is said to occur under confined, or artesian, conditions.

All fresh ground water in the Dare Beaches Sanitary District, at least to the depths penetrated by the test wells, is derived from the precipitation falling on the area. According to data collected by the U. S. Geological Survey, aquifers that crop out on the mainland to the west and that extend beneath the "outer banks" contain saline water in Dare County.

Use of Ground Water

Present ground-water supplies in the sanitary district are obtained from shallow sand-point wells most of which are less than 40 feet deep. Practically all the water drawn from these wells is returned to the ground through septic tanks. Water is used principally for domestic purposes in the houses, motels, and restaurants of the area. There is no industrial consumption of water, and little water is used for irrigating lawns or gardens.



Map showing the best potential aquifer sands and largest body of fresh water indicated by the test drilling program.

Figure 3

Saline Contamination

Fresh ground water in the Dare Beaches Sanitary District, recharged by rainfall, occurs as a lens lying above salt water, as shown diagrammatically in figure 4. Excessive withdrawal of the fresh water will result in the encroachment of saline water into the fresh-water aquifer being pumped. The extent of encroachment depends chiefly upon the elevation of the water table relative to sea level, which is governed mainly by the amount and distribution of withdrawals. These and other pertinent factors must be considered prior to determining the amounts of fresh water that may be safely withdrawn and the location and design of supply wells and well fields.

The theoretical relationship concerning the depth to the fresh-salt-water interface in homogeneous deposits is expressed by the Ghyben-Herzberg equation as follows: $h = t/g-1$ where h = depth of fresh ground water, in feet, below sea level, t = fresh-water head, in feet, above sea level, g = specific gravity of sea water. The specific gravity of fresh water is considered to be 1. Brown[1] pointed out that the Ghyben-Herzberg principle "appears to apply particularly to small islands and narrow land masses that are made up freely pervious material, especially sand." Therefore it would be expected to apply rather closely on Bodie Island. The specific gravity of sea water is ordinarily about 1.025. Substituting this value for g, the ratio of the depth of fresh water below sea level to the head of fresh water above sea level is 40 to 1. Salt water having a density different from 1.025 would, of course, give an h value differing from 40. But the 40-to-1 ratio is used in the theoretical assumptions, as it is assumed that 1.025 is the most probable value for the specific gravity of sea water in the area.

Water-level measurements in test wells indicate a fresh-water head ranging from less than 1 foot to more than 8 feet above mean sea level. (Sections across the island relating the water table to topography are not included in this report. Water-level measurements were made over a period of 3 months; such sections would be erratic because of fluctuations caused by recharge and discharge during this period.) Application of the theoretical ratio suggests a depth of more than 300 feet of fresh water in some locations. However, water samples collected from test wells indicate that the theoretical values differ from field values. In some wells where the fresh-water head is 4 to 5 feet above sea level, salty water occurs at a depth of as little as 15 feet below sea level. In some wells salinity decreased with depth, and in other wells zones of saline water were interstratified with zones of fresher water. The lack of agreement between theoretical and field data may result from one or more of the following modifying factors:

1. The wide range of permeabilities of the sediments tends to negate the establishment of a condition of equilibrium between fresh and salt water.
2. Sufficient time may not have elapsed since total inundation of the land mass to allow the fresh-salt-water system to have reached a state of dynamic equilibrium.
3. Occasional inundation of parts of the land mass by high tides has resulted in a stratification and mixing of fresh and salt water.
4. Near the beaches a zone of diffusion rather than a sharp interface exists as a result of the mixing action of tidal forces.

The effects of some of these modifying factors are discussed in the following section.

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[1] Brown, J. S., A study of coastal ground water, with special reference to Connecticut: U. S. Geol. Survey Water-Supply Paper 537, p. 16-17, fig. 2, 1925.

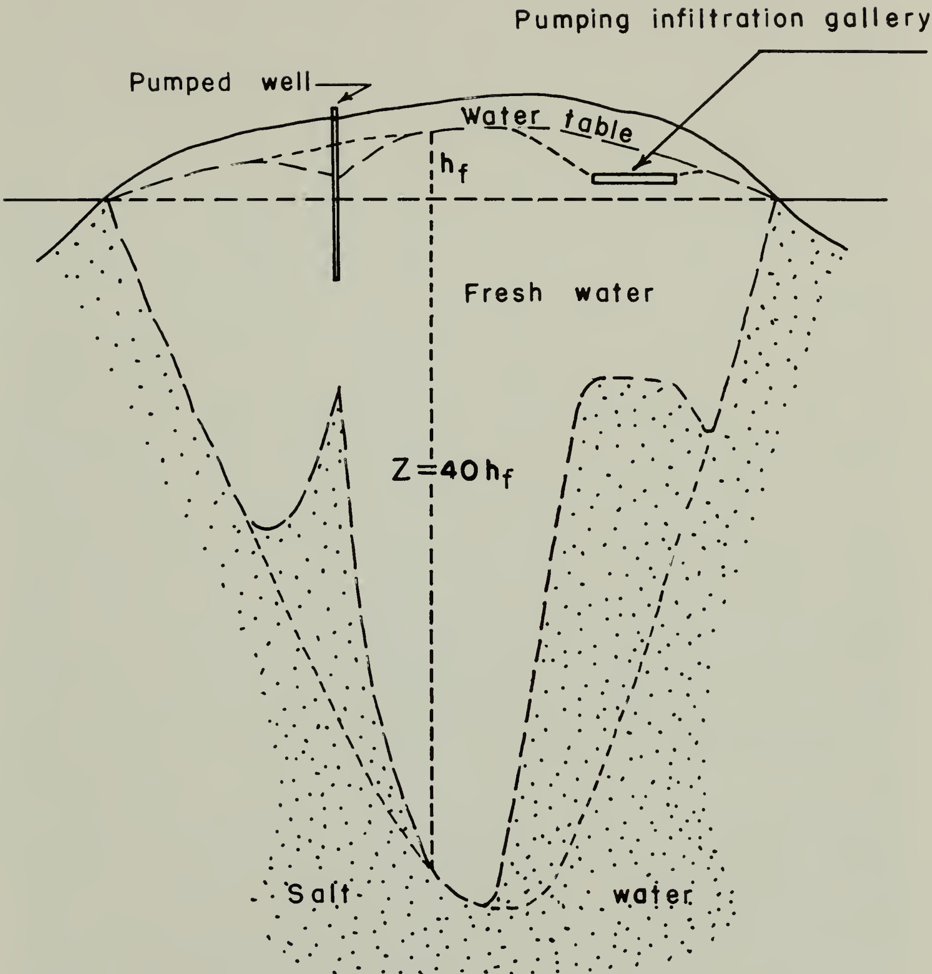

Diagram showing the theoretical relation of fresh water to salt water in a sandy island under pumping conditions

Figure 4

Aquifers

Fresh ground water occurs in the sanitary district, at least to the depths penetrated by test wells, in all three of the lithologic units described previously -- the lower and upper sand units and the beach gravel in the upper unit. Most of the wells in the district tap the upper sand and the beach gravel interfingered with the sand unit. These two lithologic units are referred to as the upper aquifer in this report. A few wells tap the lower silty sand unit, referred to as the lower aquifer in this report.

Lower aquifer.-- The lower aquifer extends at least to the shores of the island. Its thickness is not known, as no test wells penetrated it completely. Water in the lower aquifer occurs under semiartesian conditions because the relatively impermeable layers of silt act as partial confining beds. Thus the water levels in wells penetrating this aquifer do not represent the top of the zone of saturation, but rather the height of a column of water that will be supported by hydrostatic pressure in the aquifer at a given point of penetration. The lower aquifer is recharged by downward percolation of water from the upper aquifer. The confining character of the silty layers differs at any one location, being dependent upon the thickness and continuity of silt beds. Within that part of the aquifer containing the fresh-water lens, the salinity of water apparently is inversely proportional to the permeability of the sand in which it occurs. Clean sand of high permeability contains water having a low chloride content, whereas silty sand of relatively low permeability contains water having a higher chloride content. Evidently, the zones of high silt content and relatively low permeability retard the flushing action of percolating ground water to the extent that the silty zones still retain a fraction of their residual salt water. The lower aquifer is not considered suitable as a source for ground water supply for two reasons: (1) the quality of water from any proposed well in this aquifer cannot be predicted from present data, owing to the variation in salinity of the water, and (2) the danger of salt-water encroachment is critical in the parts of this aquifer that contain fresh water owing to the proximity of the underlying fresh-salt-water contact.

Upper aquifer.-- Water in the upper aquifer occurs under water-table conditions; that is, the water levels in wells penetrating this aquifer represent the top of the zone of saturation, or water table. The water table rises in response to recharge by precipitation and falls in response to discharge into the ocean and sounds, leakage into the lower aquifer, and loss by evapotranspiration. The thickness of the upper aquifer ranges from 25 to 70 feet; its average thickness is about 45 to 50 feet. Fresh water occurs throughout the upper aquifer except in some areas adjacent to the ocean or sounds. Saline water in the upper aquifer at these locations may be explained by (1) encroachment of salt water due to overpumping of existing wells in the area, or (2) mixing of fresh and salt water by inundation during storms or as a result of diffusion caused by tidal movements.

Ground-Water Supply Systems

Ground-water supplies from water-table aquifers subject to salt-water encroachment may be obtained safely from shallow wells or infiltration galleries. A discussion of the advantages and disadvantages of the two types of ground-water supply systems in relation to their use in the Dare Beaches Sanitary District follows.

Shallow wells offer the advantage of low initial cost and ease of installation. They may be driven, jetted, bored, or drilled to the desired depth. If a supply area becomes contaminated by salt-water encroachment, the shallow-well supply system may be relocated in an uncontaminated area relatively easily without long-term interruption of the supply.

The major disadvantage of using shallow wells in an area liable to salt-water encroachment is the need for continual regula-

tion of the pumping rate of each well. It has been previously mentioned (p. 8) that the height of the water table above sea level in a supply area is the primary factor that determines whether or not salt-water encroachment will occur as a result of the withdrawal of fresh water. Salt water may encroach if the water level in one or more wells in a supply area is drawn down below sea level. The water-table aquifers show rapid response to changes in discharge or recharge; this may require frequent adjustment of the pumping rate in individual supply wells in order to maintain the pumping levels above some predetermined horizon of maximum drawdown. For example, during a period of abundant recharge by rainfall, the water table in the area would be relatively high and more water could be withdrawn from each well without exceeding the predetermined maximum allowable drawdown than could be withdrawn during a period of deficient rainfall when the water table would be relatively low.

Infiltration galleries are systems of well screen and casing laid horizontally in trenches below the water table. The trenches are backfilled with coarse material and water is pumped from these "horizontal wells."

Properly installed infiltration galleries eliminate the danger of vertical salt-water encroachment. For example, if an infiltration gallery is laid at an elevation of 2 feet above sea level, the water table at the gallery cannot be drawn down, by pumping the gallery, below an elevation of 2 feet above sea level. Thus, 2 feet of fresh-water head above sea level is sufficient to prevent vertical salt-water encroachment into the fresh-water supply.

The major disadvantage of an infiltration-gallery supply system is the difficulty of installation in unconsolidated sand as compared with the installation of a shallow-well system. For example, if infiltration galleries were installed in the dune areas covered by this report, a trench 15 to 20 feet deep might be required to install them at the proper level because the water table is that deep below land surface. Caving of the dune sand into a trench of this depth would make installation very difficult. Their installation would, of course, be simpler in areas where the water table was closer to the land surface. Once installed, infiltration galleries also are more difficult to relocate than shallow wells if the supply area is contaminated by overland or lateral salt-water encroachment.

This investigation, due to the limited time available, was directed primarily toward evaluation of ground-water supplies available to shallow wells. Accordingly, the remainder of this report deals largely with shallow well systems. However, the writer considers that infiltration galleries placed in the vicinity of the fresh water lakes would offer advantages that might justify additional data collection to determine their spacing and expected yield. This is discussed in the section entitled "Infiltration-gallery supplies" (p. 14).

Quantitative Ground-Water Studies

The withdrawal of water from an aquifer causes water levels to decline in the vicinity of the point of withdrawal. It has been pointed out in the discussion of salt-water encroachment (p. 8) that the height of the water table above sea level is the primary factor that will determine whether salt-water encroachment will occur in the area. The amount by which water levels are lowered by pumping is governed by several factors. These include (1) the rate of pumping, (2) the water-transmitting and water-storage characteristics of the aquifer, (3) the extent of the aquifer, and (4) the location and quantity of recharge and natural discharge.

Aquifers function in two capacities -- as conduits that transmit water and as reservoirs that store water. The measure of an aquifer's capacity to transmit water is its coefficient of transmissibility, which is defined as the rate of flow of water, in gallons per day, at the prevailing water temperature, through each

vertical strip of the aquifer 1 foot wide having a height equal to the thickness of the aquifer, under a unit hydraulic gradient. The measure of an aquifer's capacity to store water is its coefficient of storage, which is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. These coefficients may be determined by means of pumping tests and may be used to estimate the resultant decline in water levels in response to various rates of pumping.

Pumping test.-- A pumping test was made in the sanitary district area to obtain data for computing the above mentioned coefficients. A production well (P-1) and observation wells (0-1 to 0-5) were constructed at a location where the upper aquifer is 62 feet thick and is composed entirely of clean medium to fine-grained quartz sand (pl. 1, fig. 3). Observation wells 0-1, 0-2, and 0-3 were used to record the drawdown caused by pumping well P-1, and observation wells 0-4 and 0-5 were used to determine the extent of vertical salt-water encroachment due to the pumping of well P-1. Wells P-1, 0-1, 0-2, and 0-3 were 38 feet deep. Well 0-4, screened near the bottom of the upper aquifer, was 55 feet deep. Well 0-5, screened in the lower aquifer, was 73 feet deep.

In the period January 12-15, 1959, well P-1 was pumped at a steady rate of 50 gpm for 72 hours, and the resulting drawdowns in wells 0-1, 0-2, and 0-3 were recorded. Water samples for chloride determinations were taken hourly throughout the test from wells P-1, 0-4, and 0-5.

The chloride content of the water from well P-1 ranged from 14 to 17 ppm during the 72-hour pumping period. During the same period the chloride content of the water from well 0-4 ranged from 16 to 26 ppm, and the chloride content of the water from well 0-5 fluctuated between 416 and 516 ppm. No consistent trend in the chloride content of waters from wells 0-4 and 0-5 could be related to the pumping of well P-1.

Analysis of the pumping test data and laboratory determination of permeability and specific yield for samples of the upper aquifer from the area indicate the following:

The upper aquifer in the area of the pumping test has a coefficient of transmissibility of about 15,000 gallons per day and a coefficient of storage of about 0.3.

Quality of Water

Measurements of the chloride content of ground water in an area adjacent to salt water are used to detect salt-water encroachment. Accordingly, the chloride content was determined for all water samples collected during the test-drilling program (table 1). For the purposes of this investigation, water having a chloride content in excess of 250 ppm was arbitrarily considered to have been contaminated by some form of salt-water encroachment.

A water sample was collected from well P-1 at the end of the 72 hour pumping test and analyzed by the Quality of Water Laboratory of the U. S. Geological Survey, Raleigh, N. C. The analysis is shown in table 2.

The iron (Fe) content of the water from well P-1 indicates that treatment would be required to make this water suitable for domestic use. Water having an iron content of more than 0.3 ppm is objectionable for domestic purposes because excessive amounts of iron cause staining of porcelain and enamel ware, plumbing fixtures, and fabrics.

The iron content of 2.4 ppm in the water from well P-1 (depth 38 feet) is representative of the iron content of water from this depth at any location in the upper aquifer within the potential supply area delineated in figure 4. Numerous analyses of the iron content of waters from test wells in the area indicate that the iron content of water from the upper aquifer progressively decreases with depth. Generally, an iron content ranging between 3 and 7 ppm may be expected in water samples taken above a depth of

30 feet below land surface in this aquifer. At 30 to 40 feet below land surface, an iron content ranging between 1 and 3 ppm is indicated by the analyses. The iron content of water occurring between 40 feet below land surface and the contact between the upper and lower aquifers diminishes to a minimum of about 0.5 ppm iron. Additional work is currently in progress in the area to determine the relationship and effect of aquifer composition on the apparent stratification in the iron content of water in the aquifer. The analysis in table 2 indicates that no other dissolved constituent in the water from well P-1 is present in amounts that would require treatment.

Hydrogen sulfide (H_2S), although not present in detectable amounts in the areas in which the pumping test was made, does occur at places in the upper aquifer. Water having a hydrogen sulfide content in excess of 0.5 ppm has a disagreeable odor. If future supply wells yield water having an excessive hydrogen sulfide content, it can be lowered by aeration.

Water in the upper aquifer may be colored due to the presence of organic material occurring near the top of the upper aquifer. The degree of coloration at any particular location cannot be predicted, but generally, it will be sufficiently high to require treatment for its removal.

An analysis of a water sample taken from the bottom of Fresh Water Lake (at a depth of 15 feet) is also included in table 2. The lake water is considerably lower in dissolved solids than the water from a depth of 15 feet in the upper aquifer.

"Safe yield".-- The term "safe yield" as used in this report is defined as the rate at which fresh ground water can be withdrawn from a well, or group of wells, pumped at a constant rate without causing salt-water encroachment.

Analysis of the pumping-test data indicates that water moves upward from the lower aquifer in response to lowered water levels in the upper aquifer. In addition, test drilling indicates that the lower aquifer contains salt water at depth. Therefore, to guard against the possibility of vertical salt-water encroachment into the upper aquifer, the pumping water level in future supply wells tapping the upper aquifer should be maintained above sea level.

Prior to the pumping test that was conducted at well P-1, the water level in the well was 5.02 feet above mean sea level. Seventy-two hours of steady pumping, at a rate of 50 gpm, resulted in a drawdown of 6.99 feet (1.97 feet below mean sea level). Although there was no indication of salt-water encroachment as a result of pumping well P-1, continued pumping with a pumping level below mean sea level would result in such encroachment by upward movement of saline water from the lower aquifer.

The potential supply area shown in figure 3 is restricted to the area where the upper aquifer is composed entirely of medium to fine-grained clean sand, for the following reasons: (1) analysis of the pumping-test data indicates that wells should be located at least 1,500 feet from any lateral source of salt water. This restriction eliminates much of the area where the interfingered beach gravel in the upper aquifer attains its greatest thickness, (2) the part of the upper aquifer composed entirely of clean sand, particularly in the middle and western parts of the island near the Fresh Water Lake and the Nags Head Woods, is upgradient from and subject to less danger from pollution by waste disposal than that part of the upper aquifer containing beach gravel which underlies developed areas.

The data obtained from the pumping test were used to compute the amount of water that a well tapping the upper aquifer might yield without causing its pumping level to decline below 2 feet above mean sea level. These computations indicate that at least 25 gpm could be obtained from each well without exceeding the drawdown mentioned above; they further indicate that wells should be at least 1,000 feet apart to avoid mutual interference. As an additional safeguard against salt-water encroachment, supply wells tapping this aquifer should not exceed a depth of 30 feet below

mean sea level. The potential supply area (fig. 3) has sufficient areal extent for the location of wells in 2 parallel lines -- the lines spaced 1,500 feet apart and the wells in each line spaced 1,000 feet apart. With a yield of 25 gpm from each well and the wells spaced as suggested above, at least 650 gpm may be safely withdrawn from the upper aquifer in the potential supply area.

Infiltration-gallery supplies.-- The advantages and disadvantages inherent in both shallow-well supply systems and infiltration-gallery supply systems have been discussed in the section entitled "Ground-water supply systems." The field work for this investigation was directed primarily toward determining the quality and quantity of water that may be obtained from shallow wells in the Dare Beaches Sanitary District area. Accordingly, the preceding section entitled "Safe yield" was concerned with water supplies from shallow wells. However, the writer considers that the advantages offered by infiltration galleries in the area of investigation justify their consideration as an alternate source of supply. These advantages apply particularly to infiltration-gallery supplies from the fresh water lakes and is based on the following factors:

(1) The lakes have large storage capacities. The volume of the largest lake (Fresh Water Lake) was measured by the writer at a time when the lake surface was at 9.4 feet above mean sea level and the average maximum depth of the lake was 15 feet. At that time, Fresh Water Lake contained approximately 90,000,000 gallons of water and its surface covered approximately 35 acres. The other unnamed fresh water lakes in the potential supply area are smaller than Fresh Water Lake but their aggregate water volume would be sizeable. The lakes are recharged by rainfall and by inflow from the upper aquifer.

(2) A chemical analysis of water from Fresh Water Lake indicates (table 2) that the lake water is considerably lower in total dissolved solids, particularly iron, than water from the upper aquifer. Withdrawal of water from the lakes by infiltration galleries would result in accelerated recharge to the lakes from the upper aquifer; after a prolonged period of withdrawal the chemical quality of lake water would be expected to closely approximate the chemical quality of water from the upper aquifer. However, consideration of the low ratio of expected withdrawal to the volumes of the lakes, the high rate of recharge to the lakes, and the effects of lake storage time on the iron content of the lake water suggests that the dissolved solid content of water obtained from infiltration galleries would be lower than the dissolved solid content of water from a shallow-well supply system.

(3) The centralized and relatively protected location of the lakes would allow greater centralization of the water-supply system than would a shallow-well supply system.

Salt-Water Encroachment.-- Production wells in the potential supply area (fig. 3) should be located at a sufficient distance from the ocean or sound to minimize the danger of lateral salt-water encroachment. But the possibility and early detection of such encroachment should be considered and safeguards established. In addition, the pumping-test data indicate that the lower aquifer, does not act as a seal to prevent the vertical encroachment of salt-water into the upper aquifer under pumping conditions. Thus salt-water encroachment is a real and continuing danger in the potential supply area.

Early detection of any salt-water encroachment in the area is necessary in order to prevent the loss of the entire ground-water supply. The following suggestions are designed to insure early detection of either vertical or lateral salt-water encroachment.

1. The water level in at least one observation well, located near the supply area and at least 1,500 feet from the nearest supply well, should be recorded weekly.
2. The chloride content of the water from each supply well should be determined weekly.

3. The chloride content of the water from two monitor wells, one located between the supply area and the ocean and one between the supply area and the sound, and screened at the same zones as the supply wells, should be determined weekly.

4. Determinations of the chloride content of the water from one monitor well, located in the supply area and screened at least 60 feet below mean sea level, should be made weekly.

These observations should be made throughout the first year of pumping. At the end of this period the tabulated data should be analyzed to determine the effect of pumping on the ground-water levels or on the movement of salt-fresh water interface in the area.

CONCLUSIONS

1. The test-drilling and water-sampling program indicates that the only fresh ground water in the area occurs in those deposits that lie in a zone whose base is about 100 feet below mean sea level. These deposits may be divided into a lower aquifer and an upper aquifer. The lower or silty-sand aquifer underlies the entire area. The upper aquifer is composed of a clean-sand unit which is present throughout the entire area and a beach-gravel unit that is interfingered with the clean sand adjacent to the ocean. The upper aquifer has an average combined thickness of 45 to 50 feet.

2. The water in the lower aquifer is salty at some places. The salinity of water in this aquifer apparently is inversely proportional to the permeability of the material in which it occurs. The upper aquifer contains fresh water except at some locations adjacent to the ocean or sound.

3. The available geologic and hydrologic data indicate that at least 650 gpm may be safely withdrawn by a shallow-well supply system from the upper aquifer near the center of the island. A long-term pumping test conducted during the summer months when ground-water usage and evapotranspiration loss are at a maximum, would permit refinement of this safe-yield estimate.

4. It is considered that the advantages offered by the use of infiltration galleries placed around the shorelines of the fresh water lakes would justify their consideration as an alternate to a shallow-well supply system.

Table 1 - Chloride content, in parts per million, of water samples from the test wells.

Well No.	Total Depth (feet)	Date Sampled	Sample interval (feet below land surface)									
			10-15	20-25	30-35	40-45	50-55	60-65	70-75	80-85	90-95	100-105
			Chloride content (ppm)									
1	78	10-13-58			25	16						
2	98	10-14-58										
3	98	10-14-58							47		51	
4	98	10-14-58					31			36		
5	98	10-15-58	15									
6	98	10-15-58	6.5		16							
7	98	10-16-58			18			18			15	
8	98	10-16-58	16		26		26			27		
9	98	10-16-58	19		18	18					230	
10	98	10-17-58	28			19	22		202	890	1,870	
11	98	10-17-58	13	13	23					466		
12	98	10-20-58	15			20						
13	98	10-22-58			170		236					
14	98	10-22-58			116	302		274				
15	98	10-23-58		68	24	33	436				3,130	
16	98	10-23-58	190	570	890							
17	98	10-24-58	124	570	412		1,830		7,770		12,500	
18	98	10-24-58		29		28		20		163		
19	98	10-24-58			27			26				
20	98	10-25-58						5,110				
21	60	10-25-58			2,060		2,880					
22	98	10-27-58			1,240							

			Chloride content (ppm)							
23	98	10-27-58		2,650						
24	98	10-28-58	29			29				
25	98	10-28-58			34	62				
26	98	10-29-58	55			16				
27	98	10-29-58	12	18		14				
28	98	10-30-58		36			308			
29	98	10-30-58	19						201	
30	73	10-31-58			28			206		
31	98	10-31-58				22		260		
32	98	11-3-58								
33	98	11-3-58		88		46				
34	98	11-3-58		140		304				
35	60	11-4-58				77				
36	98	11-5-58		8.9						
37	60	11-5-58								
38	98	11-6-58	14			106	162			29
39	70	11-6-58			48	342				
40	70	11-7-58				87				
41	98	11-7-58			18		825			
42	98	11-10-58			34			775		
43	98	11-11-58	7.5		15		119			
44	98	11-12-58								
45	65	11-12-58			28		57			
46	98	11-12-58			28		142			
47	103	11-13-58					800			
48	103	11-14-58								
49	103	11-14-58								

Table 1 - Chloride content, in parts per million, of water samples from the test wells, continued.

Well No.	Total Depth (feet)	Date Sampled	Sample interval (feet below land surface)									
			10-15	20-25	30-35	40-45	50-55	60-65	70-75	80-85	90-95	100-105
			Chloride content (ppm)									
50	128	11-17-58										
51	128	11-17-58			15			17				
52	128	11-18-58			7				7.5			
53	115	11-19-58			7.5				21			1,040
54	115	11-20-58			28			22	32			
55	128	11-20-58									22	
56	128	11-21-58										
57	113	11-21-58										
58	95	11-21-58										
59	128	11-22-58										
60	128	11-24-58										
61	68	11-24-58										
62	128	11-25-58			45		1,230				22	
63	123	11-25-58				36			42			
64	128	11-26-58										
65	78	11-29-58	24		34	19						
66	83	11-29-58		44	30							
67	103	12-1-58		26	31	27	33					
68	103	12-1-58		30								
69	83	12-2-58			38	120						
70	73	12-2-58			62	60						
71	98	12-3-58	27	21	21							

			Chloride content (ppm)					
72	98	12-3-58		23		40		835
73	98	12-3-58		13		17		435
74	98	12-4-58		27	25			
75	48	12-4-58		12		15		
76	48	12-4-58		17		12		
77	88	12-5-58			18			
78	48	12-5-58		18		15		
79	43	12-5-58	18	29	32			
80	68	12-8-58			17		17	
81	103	12-8-58						
82	63	12-9-58						
83	43	12-10-58						
84	40	12-10-58						
85	40	12-10-58	30		22			
86	40	12-11-58		20	14			
87	40	12-11-58			15			
88	98	12-12-58	36	46		110		
89	40	12-15-58		22	20			
90	40	12-15-58		18		17		
91	40	12-15-58		20	15			
92	43	12-15-58			11			
93	40	12-16-58	26		19			
94	40	12-16-58		19				
95	40	12-17-58	44	24	21			
96	43	12-17-58	34		22			

Table 2 - Analyses by Geological Survey of ground water in Dare Beaches Sanitary District area, North Carolina.

(parts per million)

	1	2
Date of collection	Jan. 15, 1959	Jan. 8, 1960
Silica (SiO_2)	18	0.5
Iron (Fe)	2.4	.00
Manganese (Mn)	.04	.00
Calcium (Ca)	35	4.0
Magnesium (Mg)	2.9	2.6
Sodium (Na)	8.8	17
Potassium (K)	.9	1.3
Bicarbonate (HCO_3)	118	7
Carbonate (CO_3)	0	0
Sulfate (SO_4)	2.0	6.3
Chloride (Cl)	18	30
Fluoride (F)	.1	.1
Nitrate (NO_3)	1.1	1.5
Phosphate (PO_4)	.7	.0
Dissolved solids		
Sum	148	66
Residue on evaporation at 180° C	156	73
Hardness as $CaCO_3$	102	21
Noncarbonate	6	15
Specific conductance (micromhos at 25° C)	235	145
pH	7.0	6.6

1. Sample from the upper aquifer (well P-1)
2. Sample from bottom of Fresh Water Lake